



U.S. Department of Energy  
Energy Efficiency and Renewable Energy

# PV Module Recycling in the US

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# Not Much Actual Recycling Being Done

- Except for general requirements such as RCRA (hazardous waste definitions), no Federal actions
- Some states have regulations that might go beyond RCRA
  - California (CA) has other limits for hazardous materials
  - North Carolina and perhaps CA have recycling programs for items with cathode ray tube
- Generally, few PV companies have any policies, with a notable exception (First Solar) and some awareness of Pb-solder issues by traditional Si companies



# Reasons

- Small volume of product
- Even smaller volume of waste (given long outdoor life of modules, which postpones disposal)
- Tiny amounts of problematic materials (lead solder, and some specialty elements in newer, barely commercial technologies like selenium, cadmium)



## Compare to Energy Industry

- PV offsets other sources of energy that themselves cause pollution – implied credit?
- PV is not a classic ‘throw away’ consumer item
- PV does not consume electricity, it *produces* it
- Shouldn't PV products be compared to energy industry products (not consumer items)?



# New Industry

- New industry with much potential value; needs time to get established before regulations make a deep impact on key technical choices
  - What if short-term priorities kill off the best, new choice(s) before they get started?
  - How sure are we that we have the proper balance of good/bad in our valuations – e.g., does CdTe get a *credit* for sequestering waste Cd from zinc mining? How about improved energy-payback for thin films?
  - At worst, innovative PV module technologies can increase competition, lowering cost
- Plenty of time (30 years) to make the right decision before waste stream becomes large, due to long outdoor life of modules



## Some Actions

- Thin film companies in  $\text{CuInSe}_2$  and  $\text{CdTe}$  keep track of key regulations
  - Aim is to pass TCLP and similar tests
- First Solar has an extensive program in ES&H of  $\text{CdTe}$  modules
  - Method of separating materials in waste modules from production
  - ‘Take back’ plan for old/end-of-life modules
  - Recycling of separated materials
  - Close monitoring of manufacturing safety
- Brookhaven and NREL (DOE) have carried out key studies
  - All aspects of PV ES&H, with emphasis on cadmium, selenium, toxic gases
  - Extensive work on recycling methods and collection procedures
  - “Cadmium Issues in PV” website (<http://www.nrel.gov/cdte/>)
  - Encourage companies to proactively resolve issues



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# BNL Research on Recycling

**Vasilis Fthenakis**  
**Brookhaven National Laboratory**

- 1. Collection Infrastructure**
- 2. Technical Feasibility**





# Recycling in Other Industries

## Electronics & Telephones

Used products collected & shipped by 'reverse logistics' contractors

They are shipped as products, not as waste to service center

Usable components salvaged & precious metals reclaimed.

Only units/pieces sent for reclaiming are 'waste'

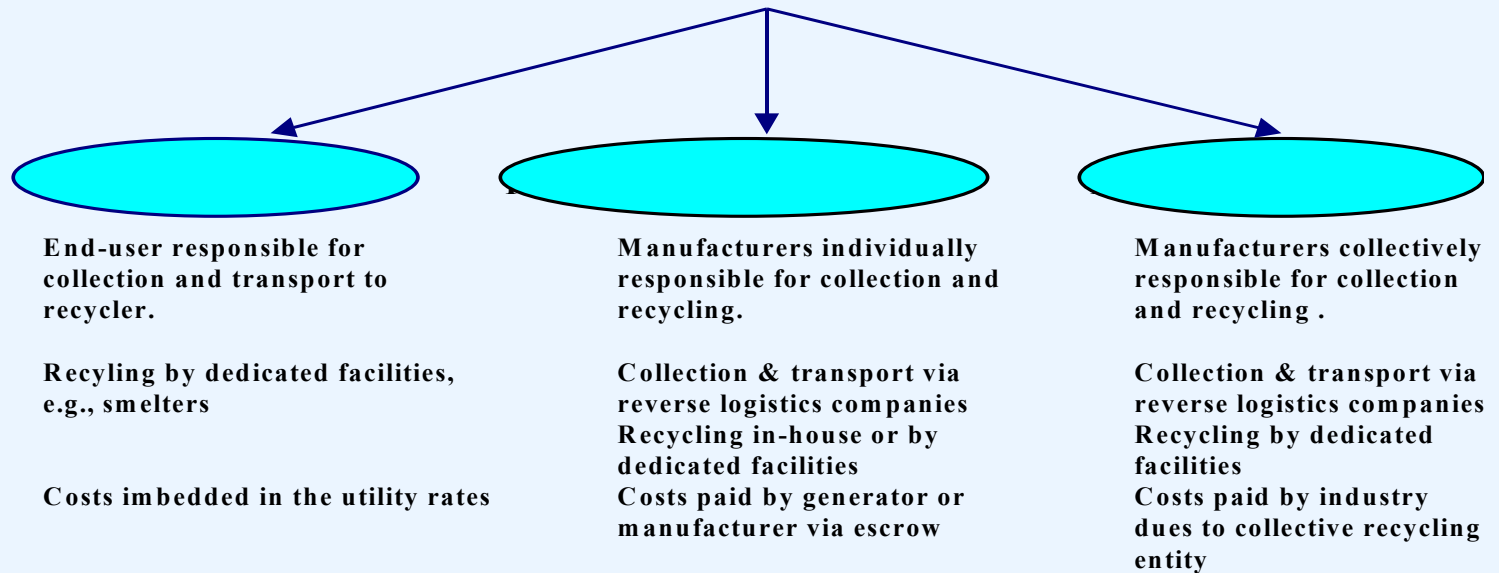
## NiCd Batteries

Industry collectively collects and recycles spent NiCd batteries in the US and Canada, via the Rechargeable Battery Recycling Corporation (RBRC).

Batteries are sent to INMETCO, which recovers Ni, Fe and Cd.

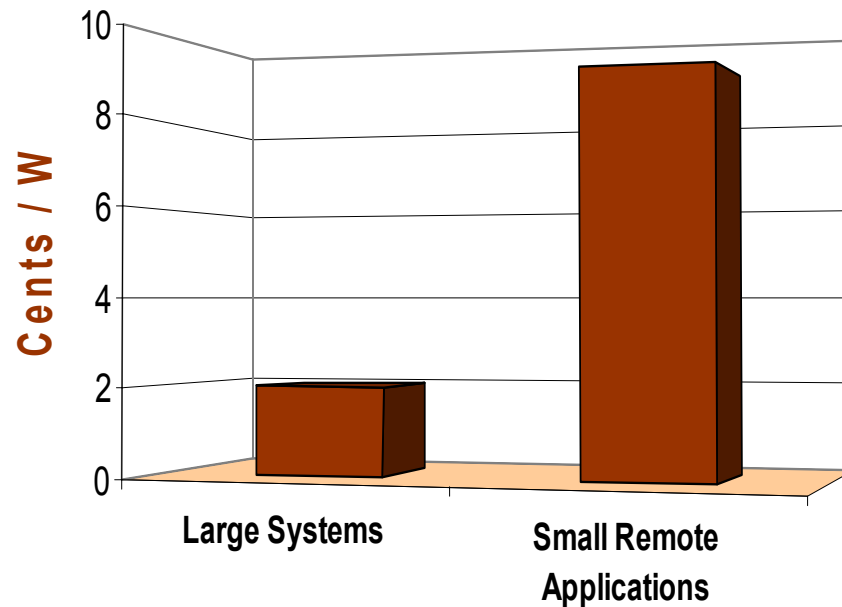


# Collection Infrastructure Paradigms





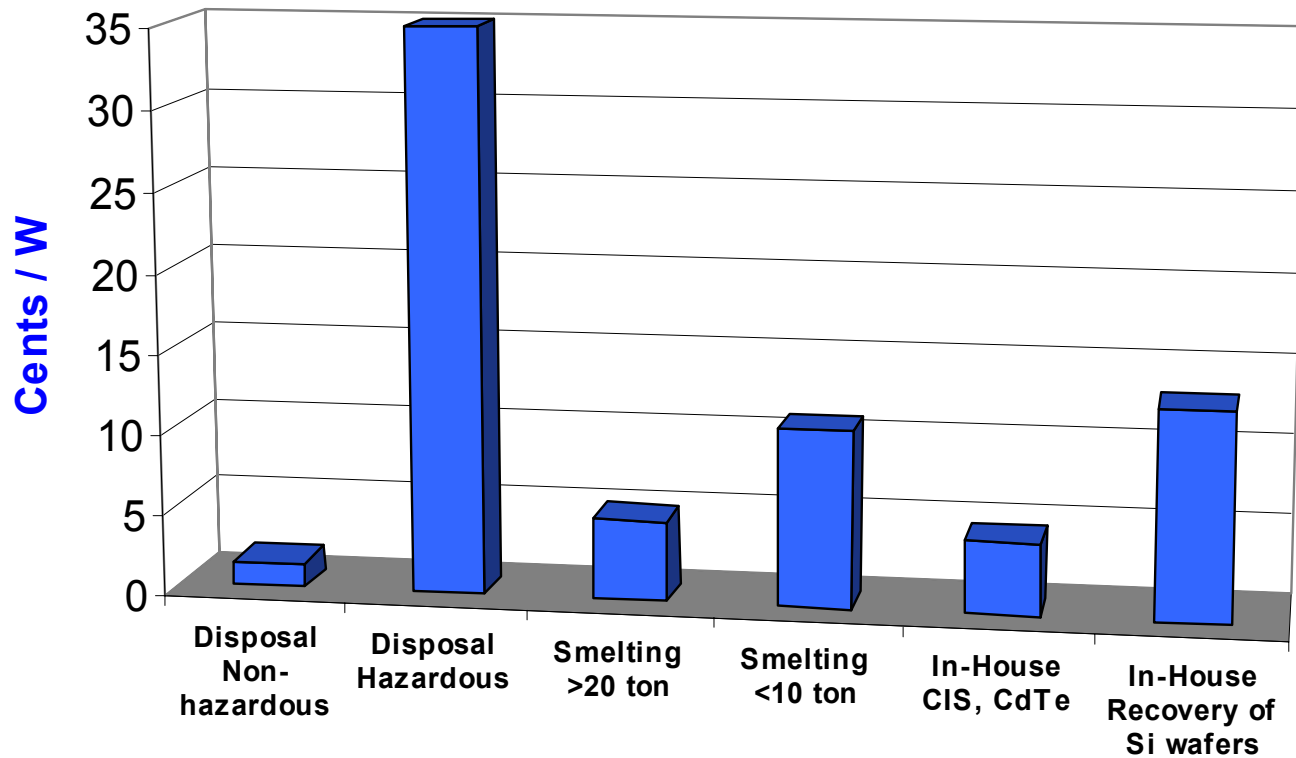
# PV Module Collection & Transportation Costs (\$1998 preliminary estimates)





# Total PV Recycling Cost

## Cost of Recycling vs Disposal





## Leaching of Cd from CdTe PV Modules

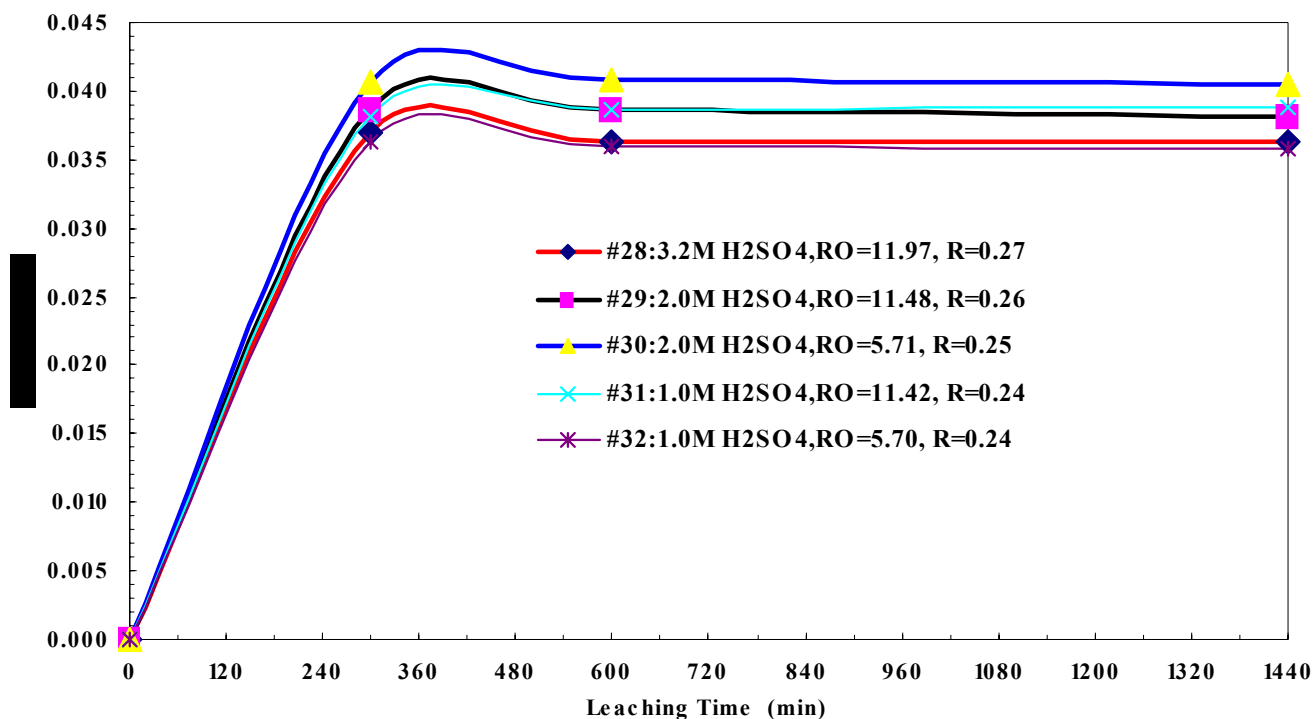
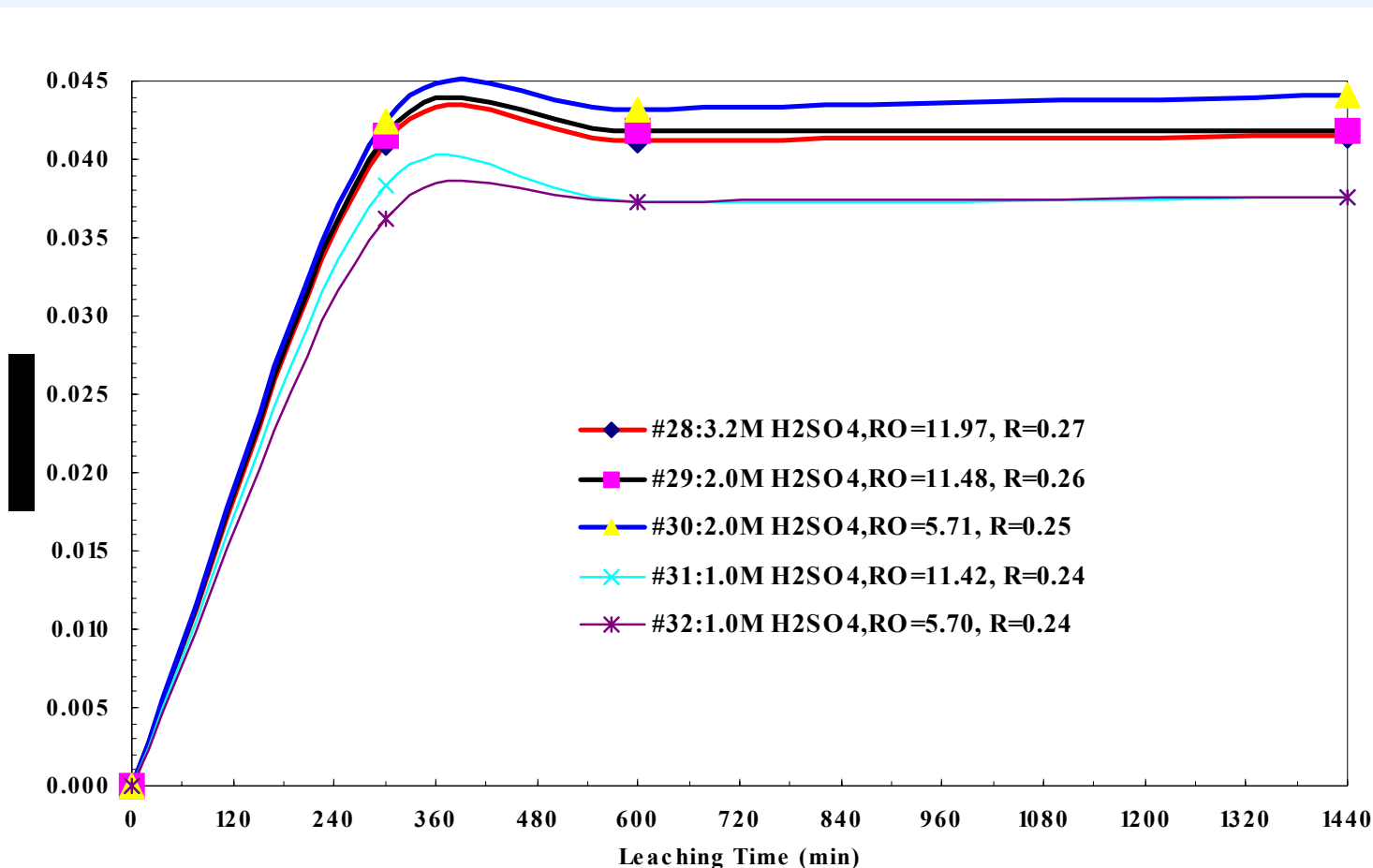


Figure 8. Cd Leaching Experiments #28,#29,#30,#31,#32. RO-ratio of H<sub>2</sub>O<sub>2</sub> to glass(mL/kg); R-ratio of leaching solution to glass(kg/kg)



## Leaching of Te from CdTe PV Modules





## Preliminary Results & Ongoing Research

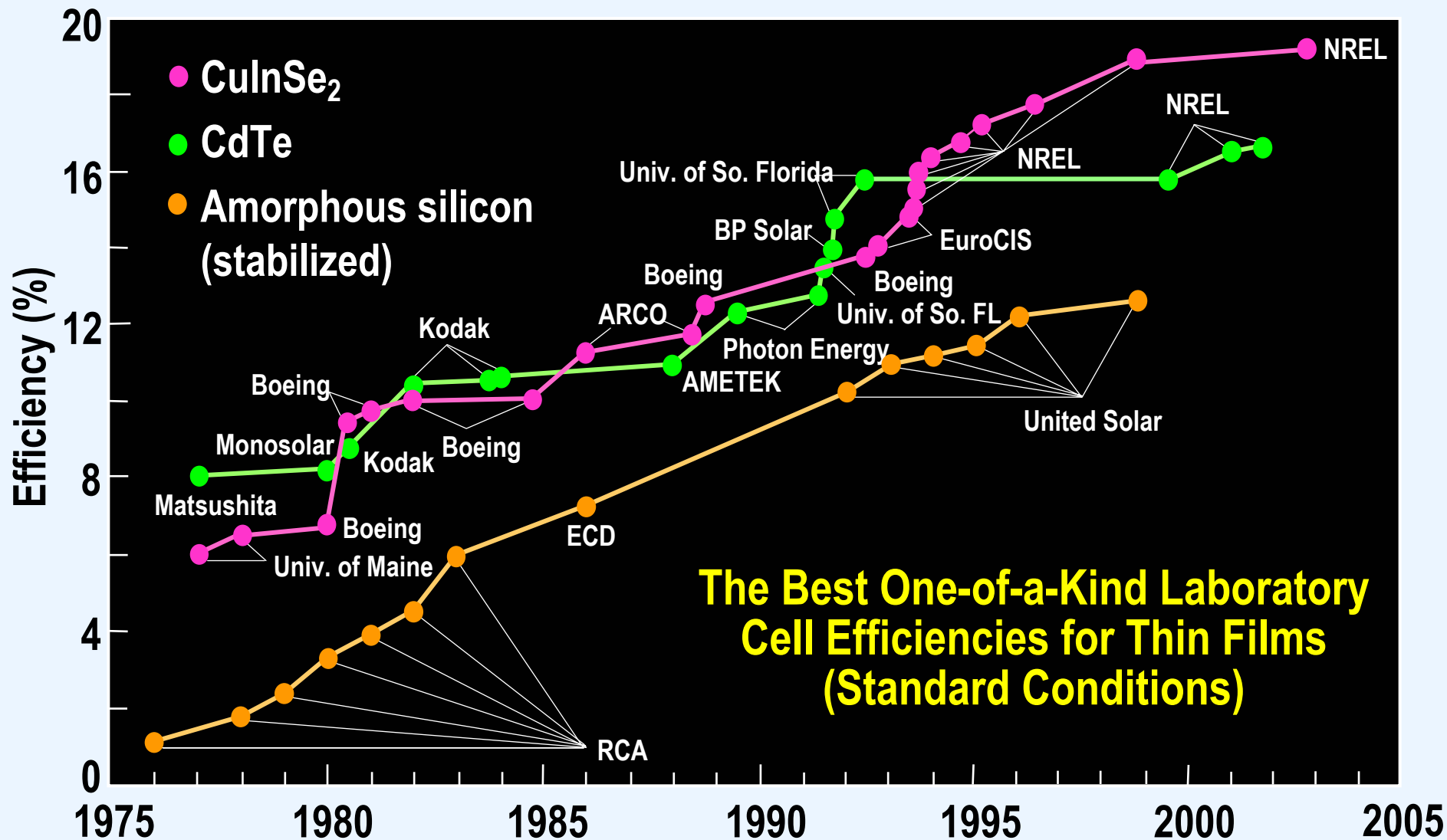
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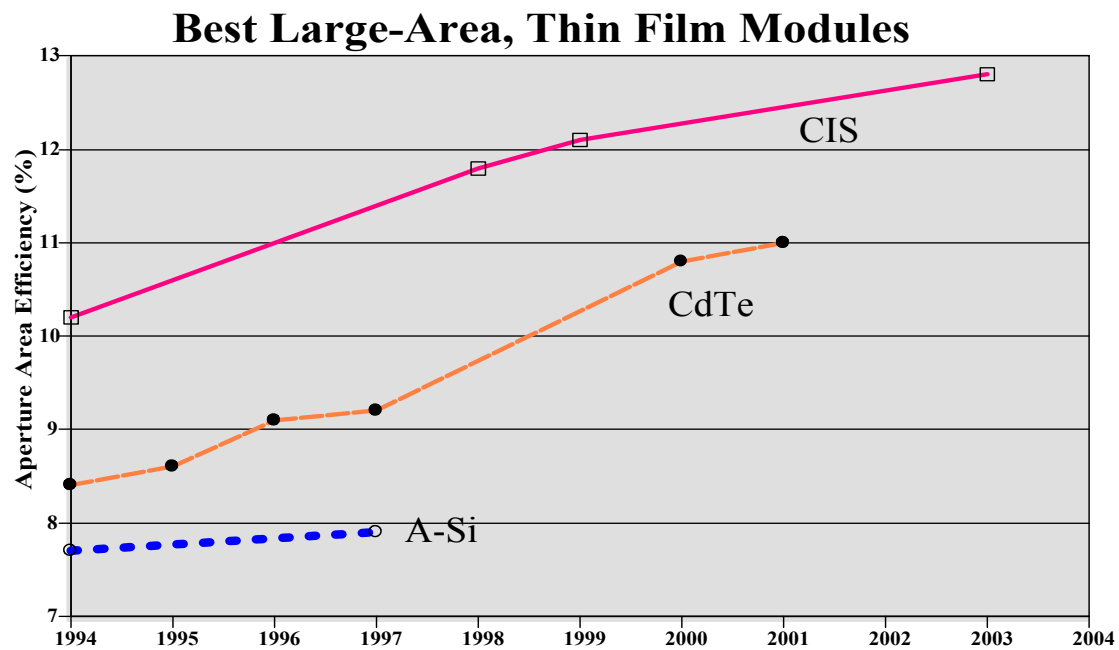
- Cd and Te can be effectively leached from fragments of PV modules with a dilute solution of  $\text{H}_2\text{SO}_4$  and  $\text{H}_2\text{O}_2$ ; this can be re-used with a small amount of  $\text{H}_2\text{O}_2$  make-up
- Using a dilute solution has cost-, safety and waste-management advantages over currently used solutions
- Preliminary results of separating Cd from Te in solution show a 99.86 to 99.99% separation



# Uniqueness of CdTe and CuInSe<sub>2</sub>

- Despite presence of Cd and Se, *crucial* PV thin film options
- Demonstrated highest efficiencies for thin films (11% and 13% at module levels, 16.5% and 19% at cells levels, respectively)
- Best potential for ambitious combination of high module efficiency and very low module costs – combining for dollar/W module potential of under 50 ¢/W, as fully developed and manufactured in volume
- These are unique technologies that cannot be replaced by those without Cd or Se (which is in the absorber, the key element of each technology)







*First Solar Advanced Thin-Film PV Modules at the  
Tucson Electric Power Array in Arizona.*



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# Shell Solar CIS Salzburg and Camarillo





# Longer Term Perspective

- If  $\text{CuInSe}_2$  and CdTe become highly successful, aim at thinner layers to keep the amounts of material small
  - Densities of Cd and Se around 3 g/cm<sup>3</sup> imply 3 g/micron-m<sup>2</sup>; @ 10% efficiency and 1 micron thickness, that's 30 MT/GW
- Layer thicknesses could drop another tenfold to twentyfold (to 0.2 microns) and still absorb 90% of the sunlight
  - Hard challenges to keep efficiencies and production yield high while making layers ultra-thin (may take 15 years to develop this option)
  - 0.2 micron layers imply about 6 MT/GW
- Due to limited global tellurium and indium supplies, aggregate amounts for cadmium and selenium in CdTe and  $\text{CuInSe}_2$  must remain small by historical standards (about 2000 MT/yr maximum) even at 100s of GW per year module production – *doesn't this mean the reward far outweighs the risk?*
  - Compare to current 20,000 MT/yr use of cadmium – for toys
- **Our goal should be to smartly facilitate the use of PV modules, including proper recycling when the industry reaches a more stable, mature level – and always avoid imposing technology choices prior to proper knowledge of tradeoffs and potentials**
  - **The risks of reducing PV module competition and reducing long-term cost viability of PV for energy significance would be otherwise too great**